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ABSTRACT

In response to empirical evidence that suggests that children use more than one strategy in transitive inference tasks, an effort was made to model strategy development as it occurs under the dual constraints of a concept of order and task demands. In the model, when a task is presented, procedural memory is searched for a strategy that is appropriate to task demands. Each strategy is associated with a confidence rating. If the rating is below threshold, reference is made to the concept of order, which is represented as an example of an ordered set retrieved from memory. Structure-mapping is used to compare the output of the strategy with the concept of order. If the output is not consistent with the concept, the strategy is modified. Structure-mapping imposes a processing load, so that a model with limited processing capacity will be restricted in the strategies it can develop. The model demonstrates that the concept of a task need not be based on universal logical principles, but can be based on specific examples from past experience. The model also shows that structure-mapping, which has been used to model analogies and transfer of learning, can be applied to strategy selection, and can account for processing of capacity limitations. (Author/RH)

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How Transitive Inference Strategies Develop from a Concept of Order: A Simulation

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Empirical evidence suggests children use more than one strategy in transitive inference tasks. The purpose of this project is to model strategy development, as it occurs under the dual constraints of a concept of order, and task demands. In the model, when a task is presented, procedural memory is searched for a strategy that is appropriate to task demands. Each strategy is associated with a confidence rating, based on its past history of dealing with such problems. If the rating is below threshold, reference is made to the concept of order, represented as an example of an ordered set retrieved from memory. Structure-mapping is used to compare the output of the strategy with the concept of order. If the output is not consistent with the concept, the strategy is modified. Structure-mapping imposes a processing load, so a model with limited processing capacity will be restricted in the strategies it can develop. The model demonstrates that the concept of a task need not be based on universal logical principles, but can be based on specific examples from past experience. It also shows that structure-mapping, which has been used to model analogies and transfer of learning, can be applied to strategy selection, and can account for processing capacity limitations.

Transitive inference (more generally, N-term series) problems consist of premises each of which expresses a relation between a pair of terms, such as aRb, bRc, cRd etc., and the participant is expected to state the rank order of one or more terms. For example, given a set of premises such as Tom is taller than Bill, and Don is taller than Tom, the participant might be asked to say who is tallest, to say whether Don is taller than Bill, or to rank order all elements. Transitive inference tasks contain many of the basic features of reasoning processes; prose comprehension is entailed in interpreting premises, then the information so obtained has to be mentally transformed and integrated. Consequently transitivity has been the subject of much research in both the adult and child cognition literature. This paper proposes a model of the way transitive inference develops in children.

A major developmental issue has been the age at which children understand transitivity. Bryant and Trabasso (1971) claimed that, contrary to Piaget (1950), 3-4 year olds could make transitive inferences if they could recall the premises (See Breslow, 1981; Halford, 1982; Thayer & Collyer, 1978 for reviews of research concerned with this claim). However it now appears that this finding may have been a false positive, based on elimination of some younger participants, and undue provision of order cues. When these factors were eliminated, it was found that 3-4 year olds did not make transitive inferences, due to inability to integrate premises (Halford, 1984; Halford & Kelly, 1984; Halford, Maybery & Bain, 1986; Kallio, 1982).

There are two contemporary models of N-term series reasoning that provide the starting point for our research. The first model (Sternberg, 1980) incorporates the main features of earlier models, and accounts for a high proportion

of the variance in solution times. The essence of it is that premises are first processed to obtain the linguistic deep structural base strings that represent their meaning. These strings are then recoded as images of ordered pairs, such as (Tom, Bill), (Don, Tom). The pivot or common term (Tom) is then located, and the pairs are integrated into an ordered triple, (Don, Tom, Bill). Sternberg's model can only produce solutions for three-term problems.

The second model (Foos, Smith, Sabol & Mynatt, 1976) postulates that the ordered set of elements is progressively constructed in short term memory (STM). The first premise is stored in STM, then there is a set of constructive operators that can be used to combine later premises with those already stored. The Foos et al. model applies to problems with more than three terms.

Both the Foos et al. and Sternberg models posit a single strategy, but there are several reasons for believing multi-strategy models might be necessary. First, multiple strategies are used in a number of simple tasks (Greeno & Johnson, 1985; Greeno, Riley and Gelman, 1984; Siegler & Shrager, 1984). For example Greeno et al., showed that even preschool children do not use a single strategy to count small sets, but used their understanding of counting to devise strategies for each task. Second, there is evidence for multiple strategies in some transitive inference and ordering tasks (Baylor & Gascon, 1974; Quinton & Fellows, 1975). Third, evidence from some of our experiments, (Maybery, Halford, Bain & Kelly, unpublished manuscript), is more consistent with a multi-strategy model.

The development of transitivity

In order to develop a multi-strategy model, mechanisms for construction and selection of strategies are required. In the proposed model, when a transitive

inference problem is presented, an attempt is made to retrieve an appropriate strategy. If no suitable strategy is available, a procedure for constructing a strategy is invoked. For any given set of task demands, an attempt is made to construct a strategy that is consistent with the way the task is understood.

Because transitive inference tasks are basically ordering tasks, understanding of the task is defined in terms of a concept of order. Some of the features that a psychologically realistic concept of order might be expected to contain are:

1. understanding of one or more asymmetric binary relations (e.g. larger than, better than).
2. each element occurs once and only once in a string.
3. end elements have the same relation to all other elements; e.g. a>b, a>c, a>d etc.
4. the position of internal elements is defined by relations to elements on both sides of it; e.g. b<a, b>c.
5. the same relation must exist between all pairs, both adjacent and nonadjacent; e.g. a>b, b>c, . . a>c, etc.

Feature 5 really includes the transitivity property of ordered sets, but is wider because it includes the idea that one relation must be used consistently throughout the set; e.g., you cannot order some elements according to height and some according to weight.

The representation of the concept of order could take many forms. Any ordered set of at least three elements can instantiate all five features of the concept of order. A psychologically realistic representation that could serve as a criterion for participants' own constructions would be a prototypical ordered set of at least three

elements, acquired through play experiences such as sorting and stacking objects varying in size.

We postulate that the concept of order develops out of play experiences with ordered sets of objects. Suppose, for example, that a child has been given a set of blocks that vary in size. One type of play experience might entail making a "staircase" out of the blocks, by trial-and-error. A concept of order can be developed by progressively noticing the relevant relations in the ordered set. For example the child might notice first that one block is bigger than all the rest, then that the second biggest block is smaller than the first one but larger than the third, and so on.

Developmental sequence

We propose the following sequence of development in children. First, children learn to categorize objects with common features at approximately one year of age (Sugarman, 1982). They learn to encode and represent relations, at least by the age of two years six months (Bullock & Gelman, 1977; De Loache, 1987).

Primitive ordering strategies in which one premise is processed at a time are evident in three-year olds (Halford, 1984). For example, given the premises Tom happier than John, John happier than Bill, Tom happier than Bill, the first step would be to produce Tom John, then Tom John Bill, then Tom Bill John. The incorrect order Tom Bill John occurs because attention is paid only to the last premise Tom happier than Bill, ignoring the previous information that John is happier than Bill.

By about five years children manage to integrate relations in a single decision. That is, they can reason that since A>B, B>C, and A>C, the correct order is ABC. This integration of two or more premises in a single decision imposes an information processing load that exceeds the capacity of most children below five

years (Halford, Maybery & Bain, 1986). Development continues after age five years, but this point marks the beginning of effective ordering strategies.

The model

This phase of our project is designed to model the transition from ineffective to effective ordering strategies. When feedback indicates an error, the confidence rating of the strategy is reduced. A new strategy will then be developed for subsequent problems.

The new strategy is developed under the dual constraints of task demands and the concept of order. The task demand is, given the premises Tom happier than John, John happier than Bill, Tom happier than Bill, to put Tom, John, and Bill in order of happiness. The concept of order is contained in previous experiences of ordered sets. The learning process entails using the concept of order to construct a strategy that conforms to task demands.

The problem is of course that the child has no strategy for producing the correct answer. The solution is to use the concept of order, based on previous experience with ordered sets, to generate the solution analogically. According to Gentner's (1983) theory, an analogy consists of a mapping from a base to a target. In this case, the concept or order is the base, and the correct order of Tom, John, Bill, the target. The required mapping is shown in Figure 1. Figure 1 shows why the order Tom, John, Bill is correct. It is because it is the only order that would produce a valid structure mapping, where validity is defined by the criterion of consistency specified by Halford (1987). To see this, consider the incorrect order, Tom, Bill, John, in Figure 2. This produces an invalid, inconsistent mapping, because "larger than" corresponds to "happier than" on two occasions, and to "sadder than" on the third

occasion. There is therefore no consistent mapping from concept of order to problem.

Analogical mapping from the concept of order to the current problem, as shown in Figure 1, provides a criterion for the correct answer to the problem. This answer is used to constrain development of a further strategy. A self-modifying system has been developed to model this learning process. This model will be described in the next section.

Implementation of the model

Our model of the transition from ineffective to effective ordering strategies is implemented in PRISM, a production system language (Ohlsson & Langley, 1986). The production system consists of two memory types: procedural and declarative. Procedural memories consist of collections of condition-action rules called productions. The conditions of a production describe configurations of elements which may be in declarative memory. The actions of a production specify modifications to the content of procedural and declarative memories. Declarative memories consist of collections of symbolic data types. The two memory types interact through a simple recognition-act cycle. When the conditions of a production are met by elements in declarative memory, the actions of that production are carried out, that is, the production fires. If the conditions of more than one production are met on any processing cycle, a conflict resolution process decides which productions will fire.

As stated earlier, strategy modification occurs under the dual constraints of task demands and the concept of order. Modification occurs when no existing strategies have a high enough confidence rating. In the production system, the confidence rating of a strategy is determined by the strength of the productions. Each

production has a strength associated with it. The strength of a production is modified with feedback. So, if a strategy produces the correct answer, the strength of the productions that produced that answer will be increased; if a strategy produces the incorrect answer, the strength of the productions that produced that answer will be decreased.

When no production whose conditions are met by the contents of declarative memory has enough strength to fire, the system enters a modification phase. The modification process occurs in two steps. First, the premises are mapped to the concept of order. This mapping process returns a consistent order for the given premises. Second, given the result of the structure mapping process and the given premises, a production is built that will produce a result consistent with the order returned by the structure mapper. On subsequent problems of the same form, this new production will produce an answer without reference to the structure mapper. Through this process, effective strategies evolve.

Starting with a primitive strategy that pays attention to the most recent premise, we will illustrate how the system modifies itself to solve problems using an integration strategy. We will use the problem presented earlier in this example. The problem is, given the premises Tom is happier than John, John is happier than Bill, and Tom happier than Bill, to put Tom, John, and Bill in order of happiness. The example is given in a simplified form to focus on the major steps in the modification process. The productions presented are actually instantiations of productions for the specific problem. The actual productions use variables and will solve many different problems.

Figure 3 shows the productions that will fire when solving this problem

using the primitive strategy. When the first premise, Tom is happier than John, is added to declarative memory, the production First_Premise will fire. This production has one condition and one action. Given a premise in declarative memory it adds an order to declarative memory. When the second premise, John is happier than Bill, is added to declarative memory, the production Add_Premise_1 fires. This production has two conditions, a premise and an order, and one action, adding a new order to declarative memory. The new Order is created by matching John in the Premise with John in the Order and appending Bill after John in the revised Order.

When the third premise, Tom is happier-than Bill, is added to declarative memory, the production Add_Premise_2 fires. This production is similar to Add_Premise_1 in that it matches a Premise and an Order on the condition side and adds a revised Order to declarative memory on its action side. The productions differ in the form of the conditions it matches and the action it performs. In Add_Premise_2, Tom in the Premise matches Tom in the Order and Bill in the Premise matches Bill in the Order, so instead of appending an item (as in Add_Premise_1) the items John and Bill are switched in the revised Order to make the order compatible with the most recent premise.

At this point, the system gives the order Tom, Bill, John as the result. Because this order is incorrect, negative, external feedback will cause the strength of the production Add_Premise_2 to be decreased. The system will solve this problem (or problems of this form) in the same manner, until the strength of the Add_Premise_2 production is too low to allow it to fire. If the Add_Premise_2 production can not fire and the contents of declarative memory do not match the conditions of any other production, the system will enter the modification phase.

As stated earlier, the strategy modification occurs in two steps. First, the current premises are mapped to the concept of order. Second, a new production is built. For this example, the structure mapper would take the premise, Tom is happier than Bill, and the order, Tom, John, Bill, and would recognize that the order is consistent with the premise. In this problem, the order does not change with the integration of the new premise, Tom is happier than Bill. Based on the structure mapper output and the current contents of declarative memory, the system builds a new production. This production is shown in Figure 4. The conditions of this production are identical to the conditions of Add_Premise_2, but the action differs. In Add_Premise_3 the Order of the items does not change. The new production will fire when this problem is presented again, and will fire in place of the weakened production, Add_Premise_2.

Conclusions

The model builds on earlier models by Sternberg and by Foos et al., but adds a number of new features. First, it is a multi-strategy model, which constructs strategies consistent with task demands, and consistent with the concept of order that has been developed through experience.

Second, it is a model that includes a learning mechanism. It can make the transition from an inadequate to a more adequate strategy by making modifications that are consistent with task demands, and with its concept of task; i.e. with the concept of order. One example of this is the transition from a strategy which takes account of the last premise only, to a strategy that integrates the last premise with stored information from previous premises.

The model is able to "bootstrap" itself up to higher level strategies using

information about ordered sets experienced in the past. This information is of a kind that could readily be acquired through play experiences with blocks and other objects that can be placed in order. The child does not require a prior understanding of the concept of order to benefit from these experiences. Structure mapping mechanisms are very important here, because they permit the child to recognize correspondences between old experiences and new tasks.

As our previous work has shown (Halford, 1984; Halford, Maybery & Bain, 1986; Maybery, Bain & Halford, 1986) structure mapping imposes a processing load. Because of this, children under five years have difficulty with mappings from one ordered set to another. This means they would be unable to develop strategies consistent with ordered sets in their experience. For example, they might recall a row of blocks stacked in order resembling a staircase, which is undoubtedly an example of an ordered set. However if they cannot recognize the correspondence between this ordered set and the premises of a problem, they will not be able to modify their strategies so as to be consistent with the ordered sets they have experienced. This means that children below age five years have difficulty developing adequate strategies for N-term series, that is transitive inference and ordering tasks, because of the processing loads that are imposed.

References

Baylor, G.W., & Gascon, J. (1974). An information processing theory of aspects of the development of weight seriation in children. *Cognitive Psychology*, 1-40.

Breslow, L. (1981). Reevaluation of the literature on the development of transitive inferences. *Psychological Bulletin, 89*, 325-351.

Bryant, P.E., & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature, 232*, 456-458.

Bullock, M., & Gelman, R. (1977). Numerical reasoning in young children: The ordering principle. *Child Development, 48*, 427-434.

DeLoache, J.S. (1987). Rapid change in the symbolic functioning of very young children. *Science, 238*, 1556-1557.

Foos, P.W., Smith, K.H., Sabol, M.A., & Mynatt, B.T. (1976). Constructive processes in simple linear order problems. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 759-766.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155-170.

Greeno, J.G., & Johnson, W. (1985). Competence for solving and understanding problems. In G. d'Ydewalle (Ed.), *Cognition, information processing and motivation* . Amsterdam: Elsevier Science.

Greeno, J.G., Riley, M.S., & Gelman, R. (1984). Conceptual competence and children's counting. *Cognitive Psychology, 16*, 94-143.

Halford, G.S. (1982). *The development of thought.* Hillsdale, NJ: Erlbaum.

Halford, G.S. (1984). Can young children integrate premises in transitivity and serial order tasks?. *Cognitive Psychology, 16*, 65-93.

Halford, G.S. (1987). A structure-mapping analysis of conceptual complexity: implications for cognitive development. *Technical report No. 87/1*. Centre for human information processing and problem-solving, University of Queensland.

Halford, G.S., & Kelly, M.E. (1984). On the basis of early transitivity judgements. *Journal of Experimental Child Psychology, 38*, 42-63.

Halford, G.S., Maybery, M.T., & Bain, J.D. (1986). Capacity limitations in children's reasoning: A dual task approach. *Child Development, 57*, 616-627.

Kallio, K.D. (1982). Developmental change on a five-term transitive inference. *Journal of Experimental Child Psychology, 33*, 142-164.

Maybery, M.T., Halford, G.S., Bain, J.D., & Kelly, M.E. (1988). *Childrens' solution processes with n-term series problems.* Unpublished manuscript, University of Queensland.

Maybery, M.T., Bain, J.D., & Halford, G.S. (1986). Information processing demands of transitive inference. *Journal of Experimental Psychology: Learning, Memory and Cognition, 12*, 600-613.

Ohlsson, S., & Langley, P. (1986). *PRISM tutorial and manual.* Irvine, CA: University of California.

Piaget, J. (1950). *The psychology of intelligence.* London: Routledge & Kegan Paul.

Quinton, G., & Fellows, B.J. (1975). Perceptual strategies in the solving of three-term series problems. *British Journal of Psychology, 66*, 69-78.

Siegler, R.S., & Shrager, J. (1984). Strategy choices in addition and subtraction: How do children know what to do?. In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 229-292). Hillsdale, NJ: Erlbaum.

Sternberg, R.J. (1980). Representation and process in linear syllogistic reasoning. *Journal of*

Experimental Psychology: General, 109, 119-159.

Sugarman, S. (1982). Developmental change in early representational intelligence: Evidence from spatial classification strategies and related verbal expressions. *Cognitive Psychology, 14*, 410-449.

Thayer, E.S., & Collyer, C.E. (1978). The development of transitive inference: A review of recent approaches. *Psychological Bulletin, 85*, 1327-1343.

Figure 1

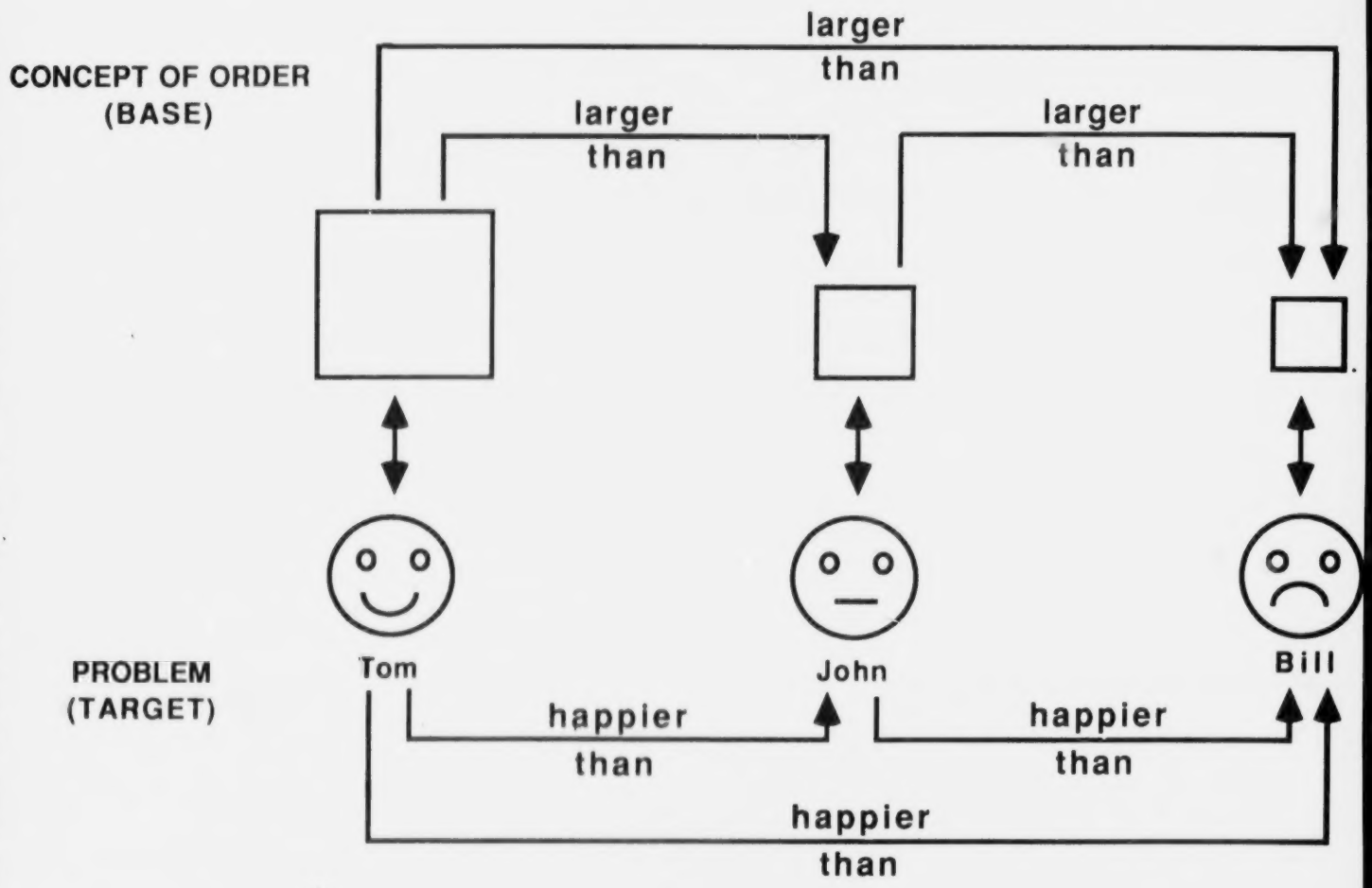
CONCEPT OF ORDER
(BASE)
larger
than
larger
than
larger
than
PROBLEM
(TARGET)
Tom
John
Bill
happier
than
happier
than
happier
than

Figure 1

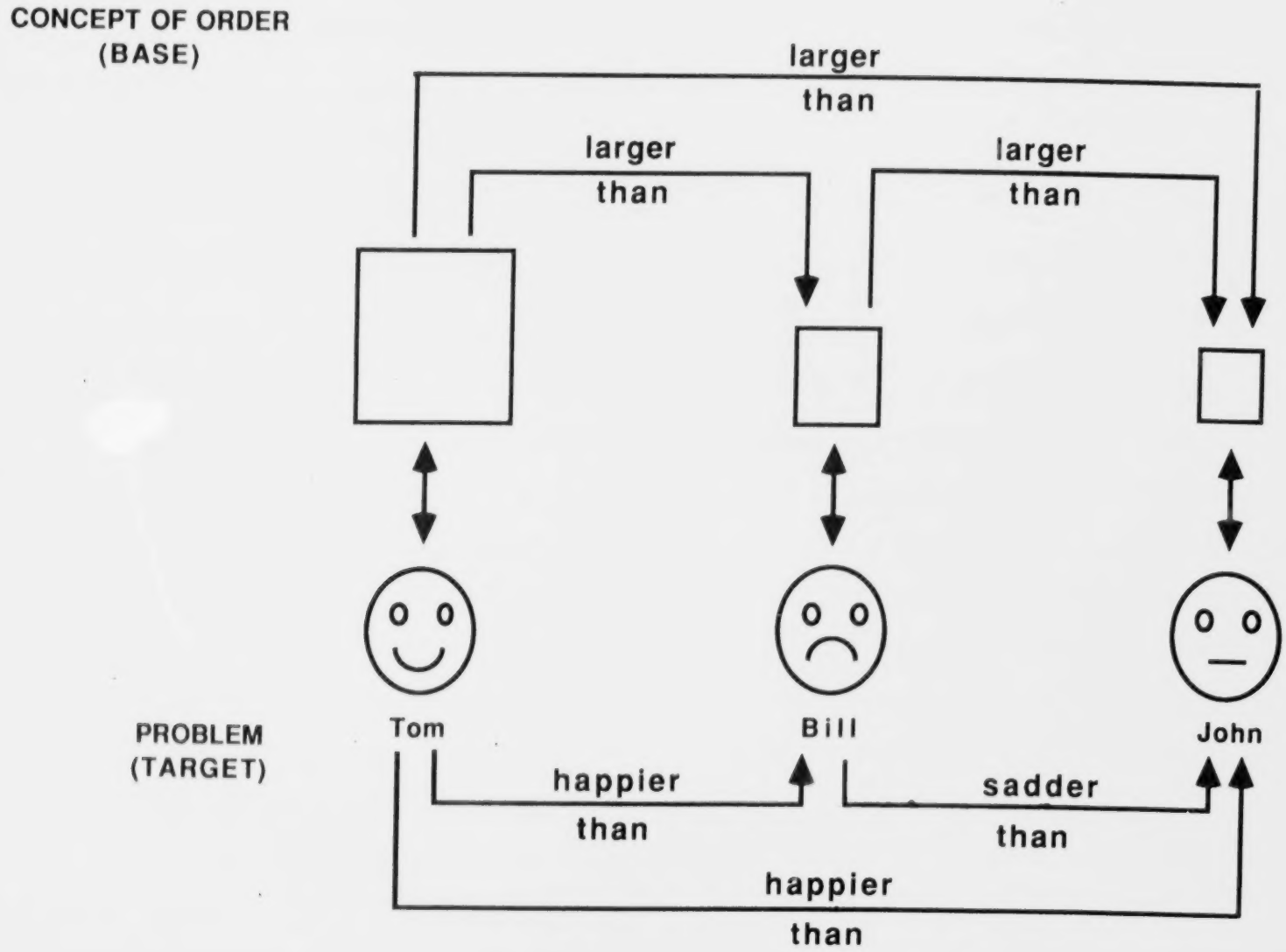
CONCEPT OF ORDER
(BASE)
larger
than
larger
than
larger
than
PROBLEM
(TARGET)
Tom
Bill
John
happier
than
sadder
than
happier
than

Figure 3.

```
(First_premise
    ((Tom happier than John))
-->
    ((add-to dm
        (Order (Tom John))]


(Add_premise_1
    ((John happier than Bill)
     (Order (Tom John)))
-->
    ((add-to dm
        (Order (Tom John Bill))]


(Add_premise_2
    ((Tom happier than Bill)
     (Order (Tom John Bill)))
-->
    ((add-to dm
        (Order (Tom Bill John))]
```

Figure 4

```
(Add_premise_3
    ((Tom happier than Bill)
     (Order (Tom John Bill)))
-->
    ((add-to dm
        (Order (Tom John Bill))]
```